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**(54) DATA READ/WRITE SYSTEMS**

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## Description

[0001] The present invention generally relates to a method and apparatus for writing data to and/or reading data from a storage surface via a tip.

[0002] An example of a such a storage device is described in "The "Millipede" - More than one thousand tips for future AFM data storage". P. Vettiger et al. IBM Journal of Research and Development. Vol.44 No.3. May 2000. As described therein, this device comprises a two dimensional array of cantilever sensors fabricated on a silicon substrate. Each cantilever is attached at one end to the substrate. The other end of each cantilever carries a resistive heater element and an outward facing tip. Each cantilever is addressable via row and column conductors. The row and column conductors permit selective passage of electrical current through each cantilever to heat the heating element thereon.

[0003] In both reading and writing operations, the tips of the array are brought into contact with and moved relative to a storage medium comprising a polymer layer such as a layer of polymethylmethacrylate (PMMA) coating a plane substrate.

[0004] Data is written to the storage medium by a combination of applying a local force to the polymer layer via each tip and selectively heating each tip via application of data signals through the corresponding row and column conductors to a level sufficient to locally deform the polymer layer, thereby causing the tip to leave an indentation or pit in the surface of polymer layer. Conventionally, the local force is applied by mechanically biasing the tip against the polymer layer. The storage medium can be thermally erased and then rewritten multiple times. To erase the storage medium, the polymer layer is heated to a level sufficient reflow the polymer layer thereby removing all indentations recorded in the storage medium.

[0005] Each heating element also provides a thermal read back sensor because it has a resistance which is dependent on temperature. For data reading operations, a heating signal is applied sequentially to each row in the array. The heating signal heats heating elements in the selected row, but now to a temperature which is insufficient to deform the polymer layer. The thermal conductance between the heating elements and the storage medium varies according to distance between the heating elements and the storage medium. When the tips move into bit indentations as the array is scanned across the storage medium, the distances between the heating elements and the storage medium reduce. The medium between the heating elements and the storage medium transfers heat between the heating elements and the storage medium. Heat transfer between each heating element and the storage medium becomes more efficient when the associated tip moves in an indentation. The temperature and therefore the resistance of the heating element therefore reduces. Changes in temperature of the continuously heated heating elements of each row

can be monitored in parallel, thereby facilitating detection of recorded bits. Conventionally, relatively long tips have been employed in the interests of achieving acceptable signal to noise ratios. However, such long tips are relatively delicate and difficult to manufacture. Also, in conventional devices, relatively soft polymers are employed in the interests of ease of writing. However, a problem associated with such materials in that deformations therein are relatively sensitive to temperature changes. Specifically, the deformations can be removed by changes in environmental temperature, resulting in a corresponding loss of data. Additionally, as the array is scanned across the surface, the tips wear against the polymer material.

[0006] According to Patent Abstracts of Japan as for Publication No. 08 297 870, a tip of a cantilever is spring biased against a recording layer and thus continuously in contact with the surface of the recording layer while moving over the surface. A voltage pulse is applied between the tip and a substrate carrying the recording layer causing the recording layer to be softened locally by a current from the tip to the substrate.

[0007] US - A 5,537,372 shows a probe storage system comprising a cantilever with a tip which is continuously pressed against the surface of a recording layer by biasing means while moving over the surface. Data are written into the recording layer by selectively heating a data item location on the recording layer beneath the tip by means of a laser. The loading force in combination with the heating will cause the tip to sink into the recording layer. EP 0 887 794 A1 presents a recording apparatus where a force is selectively applied to a tip in order to generate an indentation in a recording layer.

[0008] In accordance with the present invention, there is now provided a method for writing data to and/or reading data according to independent claim 1. This arrangement improves reading and writing sensitivity.

[0009] The tip is preferably moved alternately towards and away from the surface. This reduced wear on the tip as the tip is moved between locations.

[0010] Further enhancements to reading and writing operations are achieved in preferred embodiments of the present invention by selectively forcing the tip and the surface together coincidentally with the selective application of energy to the surface via the tip.

[0011] Additional enhancements to reading and writing operations are achieved in particularly preferred embodiments of the present invention by offsetting the selective applying of energy to the surface relative to the selective forcing of the tip and surface together.

[0012] In preferred embodiments of the present invention, improved writing performance is achieved by the selective applying of energy to the surface comprising applying energy to the surface via the tip as the tip and the surface are moved towards each other. In particularly preferred embodiments of the present invention, further improvement in writing performance is achieved by the selective applying of energy to the surface comprising

applying energy to the surface via the tip coincidentally with the tip engaging the surface.

[0013] Similarly, in preferred embodiments of the present invention, improved reading performance is achieved by the selective applying of energy to the surface comprising applying energy to the surface via the tip as the tip and the surface are moved away from each other. In particularly preferred embodiments of the present invention, further improvement in reading performance is obtained by the selective applying of energy to the surface comprising applying energy to the surface via the tip coincidentally with the tip disengaging the surface.

[0014] In especially preferred embodiments of the present invention, the selective forcing of the tip and the surface together comprises selectively generating a force field acting on the tip to urge the tip and the surface together. Preferably, the tip is moved into and out of contact with the surface by the selective generation of the force field. The force field may comprise an electric field. Alternatively, the force field may comprise a magnetic field. The energy comprises heat energy.

[0015] Viewing the present invention from another aspect, there is now provided apparatus for writing data to and/or reading data according to independent claim 13.

[0016] In particularly preferred embodiments of the present invention, the application of energy to the surface by the second transducer subsystem is offset relative to the selective forcing of the tip and surface together by the third transducer subsystem. In such embodiments, the second transducer subsystem preferably applies energy to the surface via the tip as the tip and the surface are moved towards each other by the third transducer subsystem during writing operations. The second transducer subsystem may, during writing operations, apply energy to the surface via the tip coincidentally with the tip being brought into contact with the surface by the third transducer subsystem. During reading operations, the second transducer subsystem preferably applies energy to the surface via the tip as the tip and the surface are moved away from each other by the third transducer subsystem. The second transducer subsystem may, during reading operations, apply energy to the surface via the tip coincidentally with the tip being moved out of contact with the surface by the third transducer subsystem.

[0017] In particularly preferred embodiments of the present invention, the third transducer subsystem comprises a force field generator for selectively generating a force field acting on the tip to urge the tip and the surface together. The force field generator preferably moves the tip into and out of contact with the surface by the selective generation of the force field. The force field generator may comprise an electric field generator. Alternatively, the force field generator may comprise a magnetic field generator.

[0018] The second transducer system comprises a heater for applying energy to the surface in the form of

heat.

[0019] The present invention also extends to a data storage device comprising a storage surface, a tip facing the storage surface, and apparatus for writing data to and/or reading data from locations on the surface via the tip as hereinbefore described. The present invention further extends to a data processing system comprising a central processing unit and such a data storage device connected to the central processing unit.

[0020] Preferred embodiments of the present invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a plan view of a sensor of a data storage device embodying the present invention;

Figure 2 is a cross-sectional view of the sensor when viewed in the direction of arrows A-A';

Figure 3 is an isometric view of the data storage device;

Figure 4 is a cross-sectional view of a storage medium of the data storage system after a write operation;

Figure 5 is a cross-sectional view of the storage medium after a selective erase operation;

Figure 6 is another cross-sectional view of the storage medium after a selective erase operation;

Figure 7 is an energy diagram of the surface of the storage medium;

Figure 8 is a cross-sectional view of the storage medium during a write operation;

Figure 9 is a cross-sectional view of the storage medium during a selective erase operation;

Figure 10 is another cross-sectional view of a sensor of the data storage device;

Figure 11A is a graph of spacing between the sensor and the storage medium as the sensor is addressed to successive locations on the storage surface;

Figure 11B is a graph of write signals applied to the sensor at each of the successive locations;

Figure 11C is a graph of read signals applied to the sensor at each of the successive location; and,

Figure 11D is a graph of a time varying electric field applied to the sensor at each of the successive locations.

**[0021]** Referring first to Figure 1, an example of a data storage system embodying the present invention comprises a two dimensional array of cantilever sensors 10 disposed on a substrate 20. Row conductors 60 and column conductors 50 are also disposed on the substrate. Each sensor 10 is addressed by a different combination of a row conductor 60 and a column conductor 50. Each sensor 10 comprises a U-shaped silicon cantilever 15 of a length in the region of 70  $\mu\text{m}$  and thickness in the region of micro metres. Limbs of the cantilever 15 are fixed, at their distal ends, to a silicon substrate 20. The apex of the cantilever 15 resides in a recess 70 formed in the substrate 20 and has freedom for movement in a direction normal to the substrate 20. The cantilever 15 carries, at its apex, a resistive heater element 30 and a silicon tip 40 facing away from the substrate 20. The limbs of the cantilever 15 are highly doped to improve electrical conductance. The heater element 30 is formed by doping the apex of the cantilever 15 to a lesser extent, thereby introducing a region of increased electrical resistance to current flow through the cantilever 15. One of the limbs of the cantilever 15 is connected to a row conductor 60 via an intermediate diode 80. The other limb of the cantilever 15 is connected to a column conductor 50. Row conductor 60, column conductor 50, and diode 80 are also disposed on the substrate 20.

**[0022]** Referring now to Figure 2, the tip 40 is urged against a planar storage medium in the form of a polymer layer 90 such as a film of polymethylmethacrylate (PMMA) of a thickness in the region of 40 nm. The polymer layer 90 is carried by a silicon substrate 100. An optional buffer layer 110 of cross-linked photo-resist such as SU-8 of a thickness in the region of 70 nm is disposed between the polymer layer 90 and the substrate 100. In both reading and writing operations, the tip 40 of the array is moved across the surface of the storage medium. In writing operations, the array of tips can be moved relative to the storage medium to enable writing of data over an area of the polymer layer 90.

**[0023]** Data is written to the storage medium by a combination of applying a local force to the polymer layer 90 via the tip and applying energy to the surface in the form of heat via the tip 40 by passing a write current through the cantilever 15 from the corresponding row conductor 60 to the corresponding column conductor 50. Passage of current through the cantilever 15 causes the heater element 30 to heat up. Heat energy is passed from the heater element 30 into the tip 40 via thermal conductance.

**[0024]** With reference to Figure 3, each of the row conductors 60 is connected to a separate line of row multiplexer 180. Similarly, each of the column conductors 50 is connected to a separate line of a column multiplexer 130. Data and control signals are communicated between a controller 210 and the row and column multiplexers 180 and 130 via control lines 140 and 150 respectively. The storage medium 90 can be moved in a controlled manner relative to the array in orthogonal direc-

tions via positioning transducers 160, 170, and 220. Transducers 160 and 170 effect movement of the array in a plane parallel to the surface of the polymer layer 90. Transducer 220 effects movement of the array in a direction perpendicular to the array. In operation, the controller 210 generates write signals for driving the array during writing operations, read signals for driving the array during read operations, and positioning signals for driving the transducers 160, 170, and 220 to control movement of the tips in the array relative to the surface of the polymer layer 90. The controller 210 also receives outputs from the array during read operations. In particularly preferred embodiments of the present invention, transducers 160, 170, and 220 are implemented by piezoelectric transducers, electromagnetic transducers, or a combination thereof. However, it will be appreciated that other implementations are possible. The controller 210 may be at least partially implemented by a micro-processor, micro-controller or similar control device or collection of control devices. In some embodiments of the present invention, the transducer 220 may be omitted.

**[0025]** With reference to Figure 4, the write current is selected to heat the tip 40 to a level sufficient to locally deform the polymer layer 90, thereby causing the tip 40 to indent the surface of the polymer layer 90 and leave a pit 120 of a diameter in the region of 40 nm. By way of example, it has been found that local deforming of a PMMA film can be achieved by heating the tip 40 to a temperature of the order of 700 degrees centigrade. The optional buffer layer 110 has a higher melting point than the PMMA film 90 and therefore acts as a penetration stop to prevent abrading of the tip 40 against the substrate 110. The pit 120 is surrounded by a ring 190 of polymer material raised above the polymer layer 90. A second, overlapping pit 121 is shown in phantom dotted lines.

**[0026]** The heating element 30 also provides a thermal read back sensor because it has a resistance which is dependent on temperature. For data reading operations, a heating current is passed through the cantilever 15 from the corresponding row conductor 60 to the corresponding column conductor 50. Accordingly, the heating element 40 is again heated, but now to a temperature which is insufficient to deform the polymer layer 90. Reading temperatures of the order of 400 degrees centigrade are, for example, insufficient to melt a PMMA film, but nevertheless provide acceptable reading performance. The thermal conductance between the heating element 30 and the polymer layer 90 varies according to distance between the heating element and the polymer layer 90. During a reading operation, the tip 40 of is scanned across the surface of the polymer film 90. This is achieved by moving the array relative to the polymer film 90. When the tip 40 moves into a pit 120, the distances between the heating element 30 and the polymer layer 90 reduce. The medium between the heating element 30 and the polymer layer 90 transfers heat between the heating element 40 and the polymer layer 90. Heat transfer be-

tween the heating element 30 and the polymer layer 90 more efficient when the tip 40 moves in the indentation 120. The temperature and therefore the resistance of the heating element 30 therefore reduces. Changes in temperature of the heated heating element 30 row can be monitored in parallel, thereby facilitating detection of recorded bits.

**[0027]** The aforementioned heating current is produced by applying a heating voltage pulse to the corresponding row conductor 60. Accordingly, a heating current flows through each sensor 10 connected to the row conductor 60 to which the heating voltage pulse is applied. All the heating elements 30 in the corresponding row of the array are therefore heated. Recorded data is then read out from in parallel from the heated row of sensors 10. Each row of the array is thus read sequentially according to a multiplexing scheme. In a preferred embodiment of the present invention, the storage medium provides a 3mmX3mm storage surface.

**[0028]** Turning now to Figure 5, recorded data bits can be selectively erased by forming new pits 121-124 overlapping each other over prerecorded data to be erased to substantially level the surface of the polymer layer 90. This is achieved by performing the aforementioned write operation to overwrite pits to be erased with a greater density of new pits 121-124 overlapping each other so that each new pit effectively erases the immediately preceding pit. Referring to Figure 6, the overlapping new pits 121-124 merge with each other and the pit to be erased 120 to substantially level the surface of the polymer layer 90. As mentioned earlier, the erasure need not be total. A series of ripples 200 may be left in the surface of the polymer layer 90. It is sufficient that an erased bit is not detected as a data bit during a read operation. This will of course depend on data reading sensitivity. The controller 210 is operable in an erase mode to control formation of the new pits 121-124. Returning to Figure 5, it may be acceptable in some applications for the last new bit in a sequence written to erase an unwanted data sequence, such as the bit represented by new pit 124 for example, to form part of a new data sequence to be recorded. In other arrangement, the density at which new bits are written to erase unwanted bits may be such that no new bits remain recorded in the surface.

**[0029]** Referring to Figure 7, the surface of the polymer layer 90 has a stable or ground state 230 and a metastable state 240. Applying a combination of force  $F_w$  and energy  $E_w$  to the surface via the tip 40 deforms the surface into its meta stable state 240 at the point of contact with the tip 40. With reference now to Figures 7 and 8 in combination, in a preferred embodiment of the present invention, a data bit written at a location on the surface by positioning the tip 40 at the location and applying a combination of force  $F_w$  and energy  $E_w$  to the surface via the tip 40 to deform the surface at the location. Referring to Figure 9, the data bit is then erased by positioning the tip 40 in deformation and applying energy  $E_e$  to the surface via the tip 40. Energy  $E_e$  may be less than that re-

quired to write a data bit onto the surface but greater than that required to read a data bit recorded in the surface. Alternatively, energy  $E_e$  may be similar in magnitude to energy  $E_w$ . Either way, energy  $E_e$  is sufficient to relax the surface from the metastable state 240 to the stable state 230. In the erase operation, force  $F_w$  is reduced and may be removed altogether. The relief of force  $F_w$  may be implemented via the transducer 220. With the force  $F_w$  relieved, and energy  $E_e$  applied to excite molecules in the deformed surface, intermolecular forces  $F_m$  in the surface are sufficient to push the tip 40 out as the surface relaxes into its stable state. As indicated earlier, the different combinations of energy and force required for reading, writing, and selective erasing operations are provided to the array by the controller 210.

**[0030]** With reference to Figure 10, in a preferred embodiment of the present invention, the substrate 110 is conductive and the controller 210 comprises a voltage signal generator 250 which is selectively connectable to each of the tips 40 of the array for selectively establishing a potential difference between each tip 40 and the adjacent region of the storage medium. The potential difference produces an electric field  $E$  in the region of each tip 40. The electric field  $E$  is oriented to urge the tip 40 towards the surface of the polymer layer 90. The tip 40 thus applies an additional force to the surface of the polymer layer 90 under the influence of the electric field  $E$ . The additional force can be employed to enhance both reading and, in particular, writing operations. Specifically, the additional forces permits higher data rates to be achieved in both reading and writing operations. Experiments indicate that, in the nano-meter range, viscous counter forces act against deformation of the surface of the polymer layer 90 by the tip 40 at speeds greater than around 5 microseconds. The additional force imposed by the electric field  $E$  assists in overcoming such viscous forces. The effect of the  $E$  field is further enhanced by reducing the size of the tip 40. Experiments indicate that a considerable force can be locally imposed on the surface of polymer layer 90 when the tip 40 is made considerably shorter than 1 micrometer. For such short tips, the capacitance between the sensor 10 and the substrate 100 is relatively high. For example, experiments indicate that a voltage of 10V imposed between the substrate 100 and a tip 40 of length 100nm imposes a force on the polymer layer 90 of around 0.1 mN. This force is strong enough to produce indentations in relatively soft polymers even when the tip 40 and the polymer layer 90 are at room temperature. In the absence of the electric field, the tip imposes a loading of around 0.0001 mN. Heating the tip 40 greatly reduces the penetration time in the presence of the electric field  $E$ . Specifically, experiment indicates that the additional force provided by the  $E$  field brings the data rate during writing operations into the nanosecond regime. Also, the combination of heating the tip 40 and applying the electric field  $E$  increases flexibility in performing selective bit erasing or overwriting operations. To write a bit and simultaneously erase neighboring

bits, it is desirable to maintain the temperature of the tip 40 at a relatively high level. However, to write a bit and avoid simultaneously erasing neighboring bits, it is desirable to maintain the force applied to the polymer layer 90 via the tip 40 at a relatively high level. Experiments indicate that a combination of the force imposed by the aforementioned electric field  $E$  and the heating of the tip 40 may lead to an increase in data storage density of a factor of 4.

**[0031]** With reference now to Figure 11A, in a particularly preferred embodiment of the present invention, the tips 40 are lifted off the surface of the of the polymer layer 90 between both successive reading operations and successive writing operations. By way of example, Figure 11 A demonstrates the variation in spacing  $d$  between a tip 40 and the surface of the polymer layer 90 as the tip 40 is sequentially moved through successive positions A to E on the polymer layer 90.  $d_0$  indicates the spacing when the tip 40 is in contact with the surface. Positions A to E may be equidistantly or unequally spaced on the surface according to Thus,  $d_0=0$ .  $d_1$  indicates the spacing when the tip 40 is furthest removed from the surface. The spacing  $d$  is controlled by the controller 210 via the transducer 220.

**[0032]** Referring to Figure 11 B, in a write operation for writing data bits at positions A to E, the controller 210 applies a write voltage pulse  $W_1$  across the heating element corresponding to the tip 40 as the tip 40 impacts the polymer layer 90. The write voltage pulse  $W_1$  produces a current flow in the heating element 30 of sufficient magnitude to generate enough energy at the tip 40 to locally deform the surface of the polymer layer 90 in the region of the tip 40. Enhanced deformation of the surface of the polymer layer 90 is achieved via the tip 40 impacting the surface from a remote position because additional energy is thereby imparted to the surface of the polymer layer 90. The enhanced deformation improves the definition of the recorded data. As the sequence of positions A to E are written to sequentially, the corresponding successive write pulses form a write signal  $W$  alternating between an upper voltage level  $W_1$  and a lower voltage level  $W_0$ . In some embodiments of the present invention, the write pulses  $W_1$  may be coincident with the period for which the tip 40 is in contact with the surface of the polymer layer 90. However, in particularly preferred embodiments of the present invention, the write pulse  $W_1$  is skewed relative to the period of contact between tip 40 and the polymer layer 90 such that the write voltage is applied across the heating element 30 prior to the time of impact of the tip 40 on the surface of the polymer layer 40; continues to be applied into the period for which the tip 40 is in contact with the polymer layer 90; and, is removed prior to disengagement of the tip 40 from the polymer material 90. The skewing of the write pulse relative to the contact period optimizes energy transfer from the tip 40 to the surface of the polymer layer 90, thereby enhancing the extent of deformation of the surface of polymer surface.

**[0033]** Referring to Figure 11C, in a read operation for reading data bits at positions A to E, the controller 210 applies a read voltage pulse  $R_1$  across the heating element corresponding to the tip 40 as the tip 40 is removed from the polymer layer 90. The read voltage pulse  $R_1$  produces a current flow in the heating element 30 of sufficient magnitude to generate enough energy in the region of the tip 40 to permit detection of variations in energy transfer corresponding to deformations in the surface of the polymer layer 90. Detection of recorded data is enhanced by the forces at the surface of the polymer layer 90 acting in opposition to the disengagement of the tip 40 from the polymer layer 90. As the sequence of positions A to E are read sequentially, the corresponding successive read pulses form a read signal  $W$  alternating between an upper voltage level  $R_1$  and a lower voltage level  $R_0$ . In some embodiments of the present invention, the read pulses  $R$  may be coincident with the period for which the tip 40 is in contact with the surface of the polymer layer 90. However, in particularly preferred embodiments of the present invention, the read pulse  $R_1$  is skewed relative to the period of contact between tip 40 and the polymer layer 90 such that the read voltage is applied across the heating element 30 during the period for which the tip 40 is in contact on the surface of the polymer layer 40 and is removed after the tip 40 is disengaged from the polymer layer 90 but prior to the next contact between tip 40 and the polymer material 90. The skewing of the read pulse relative to the contact period optimizes detection of data bits recorded in the deformations of the surface of the polymer material 90.

It will be appreciated, that during the reading and writing operation hereinbefore described with reference to Figures 11 A to 11C, the tips 40 of the array remain in contact with polymer layer 90 for only a relatively short period of time (typically in the range of milli- to microseconds). This advantageously reduces frictional impediments to the lateral movement of the tips 40 relative to the polymer layer 100. In addition, this limits wear to the tips 40 otherwise produced by prolonged contact between the tips 40 and the polymer layer 90. Also, this reduces demand for uniformity and accuracy in the size of the tips 40. A greater variation in spacing of the tips 40 and the polymer layer 100 can be tolerated. This reduces manufacturing costs and improves process yields.

**[0034]** With reference to Figure 11D, in an especially preferred embodiment of the present invention, both reading and writing operations are enhanced by varying the potential difference between the tip 40 and the substrate 100 between voltages  $V_1$  and  $V_0$  via the voltage signal generator 250 of the controller 210. The voltage variations are synchronized to the periods of engagement and disengagement of the tips 40 with the surface of the polymer layer 90. Specifically, the period of contact of the tip 40 with the surface of the polymer layer 90 is timed to coincide with the application of a voltage pulse imposed between the tip 40 and the substrate 110 by the voltage signal generator 250. The voltage pulse produc-

es an electric field  $\underline{E}$  in the region of the tip 40. The electric field  $\underline{E}$  is oriented to urge the tip 40 towards the surface of the polymer layer 90. The tip 40 thus applies an additional force to the surface of the polymer layer 90 under the influence of the electric field  $\underline{E}$ . In a preferred modification of this embodiment of the present invention, the voltage pulses imposed between the substrate 100 and the tip 40 are coincident, during writing operations, with the writing pulses applied to tip 40 to enhance recording of data in the polymer layer 90. Likewise, in another preferred modification of the present invention, the voltage pulses imposed between the substrate 100 and the tip 40 are coincident, during reading operations, with the reading pulses applied to the tip 40 to enhance reading of data recorded in the polymer layer 90.

[0035] In the preferred embodiments of the present invention hereinbefore described with reference to Figure 11D, variations in a potential difference are imposed between the tip 40 and the substrate 100 in correspondence with periodic engagement of the tips 40 with the polymer layer 90. However, it should be appreciated that, in some embodiments of the present invention, the periodic variation of the potential difference between the substrate 100 and the tip 40 may be employed independently of movement of the tip 40 relative to the polymer layer 90 in a direction normal to the polymer layer 90. Specifically, in such embodiments of the present invention, the voltage pulse imposed between substrate 100 and tip 40 remain synchronized to reading or writing pulses applied to the tip 40 as desired operation dictates. However, the tip 40 remains in constant contact with the surface of the polymer layer 90 as lateral movement of the tip 40 relative to the polymer layer 90 is produced via the transducers 160 and 170.

[0036] Referring back to Figure 10, is particularly preferred embodiments of the present invention, the area of the substrate is divided into individually addressable conductive zones. The voltage signal generator 250 is selectively connectable to the zones via address lines formed in the substrate 100. This enables the controller 210 to establish, via the voltage generator 250 and the accompanying address lines, the electric field  $\underline{E}$  between a selected zone and a selected tip 40 or group of tips 40. As mentioned earlier, the electric field  $\underline{E}$  may be established between the substrate 100 and the heater element 30 of the tip 40. Alternatively, the electric field  $\underline{E}$  may be established between the substrate 100 and a separate conductive platform integrated into the sensor 10 for generating the electric field  $\underline{E}$  independently of the heater 30. Addressable conduction paths formed in or on the substrate 20 and each connecting to a different one of the conduction platforms may then be employed by the controller 210 to apply the electric field  $\underline{E}$  to a selected tip 40 or group of tips 40. In other embodiments of the present invention, the electric field  $\underline{E}$  may be replaced by a magnetic force field generated by selectively passing current through conductive coils formed in or on the substrate 20 and the sensor 10 respectively.

[0037] To summarize the various embodiments of the of the present invention presented herein, a method has now been described for writing data to and/or reading data from locations on a surface via a tip comprises moving the tip between the locations on the surface. At each location, the tip and the surface are moved towards each other. Energy and force are then applied to the surface via the tip. The tip and the surface are thereafter moved away from each other. In another arrangement described herein, a force field is imposed in the region of the tip to urge the tip towards the surface.

## Claims

1. A method for writing data to and/or reading data from locations on a storage medium surface via a tip, the method comprising: moving the tip (40) between the locations on the surface; and, at each location, selectively applying energy to the surface via the tip (40) by operating a heating element (30) for heating and/or for thermal read back in a pulsed mode wherein a cantilever sensor (10) comprises the heating element (30) and the tip (40); and **characterized by** selectively forcing the tip (40) by the surface together in a pulsed mode and in synchronization with the selective application of energy.
2. A method as claimed in claim 1, comprising moving the tip (40) alternately towards and away from the surface.
3. A method as claimed in claim 1 or claim 2, comprising selectively forcing the tip (40) and the surface together coincidentally with the selective application of energy to the surface via the tip (40).
4. A method as claimed in claim 1 or claim 2, comprising offsetting the selective applying of energy to the surface relative to the selective forcing of the tip (40) and surface together.
5. A method as claimed in claim 2 and claim 4, wherein the selective applying of energy to the surface comprises applying energy to the surface via the tip (40) as the tip (40) and the surface are moved towards each other.
6. A method as claimed in claim 5, wherein the selective applying of energy to the surface comprises applying energy to the surface via the tip (40) coincidentally with the tip (40) engaging the surface.
7. A method as claimed in claim 2 and claim 4, wherein the selective applying of energy to the surface comprises applying energy to the surface via the tip (40) as the tip (40) and the surface are moved away from each other.

8. A method as claimed in claim 7, wherein the selective applying of energy to the surface comprises applying energy to the surface via the tip (40) coincidentally with the tip (40) disengaging the surface.
9. A method as claimed in any preceding claim, wherein the selective forcing of the tip (40) and the surface together comprises selectively generating a force field acting on the tip (40) to urge the tip (40) and the surface together.
10. A method as claimed in claim 9, comprising moving the tip (40) into and out of contact with the surface by the selective generation of the force field.
11. A method as claimed in claim 9 or claim 10, wherein the force field comprises an electric field.
12. A method as claimed in claim 9 or claim 10, wherein the force field comprises a magnetic field.
13. Apparatus for writing data to and/or reading data from locations on a storage medium surface via a tip, the apparatus comprising: a cantilever sensor (10) comprising the tip (40) and a heating element (30) for heating and/or for thermal read back; a first transducer subsystem for moving the tip (40) between the locations on the surface; a second transducer subsystem for selectively applying energy to the surface via the tip (40) at each location by operating the heating element (30) in a pulsed mode; and, **characterized by** further comprising a third transducer subsystem for selectively forcing the tip (40) and the surface together in a pulsed mode and in synchronization with the application of energy by the second transducer subsystem.
14. Apparatus as claimed in claim 13, wherein the third transducer subsystem moves the tip (40) alternately towards and away from the surface in synchronization with the application of energy by the second transducer subsystem.
15. Apparatus as claimed in claim 13 or claim 14, wherein the third transducer subsystem selectively forces the tip (40) and the surface together coincidentally with the application of energy by the second transducer subsystem.
16. Apparatus as claimed in claim 13 or claim 14, wherein the application of energy to the surface by the second transducer subsystem is offset relative to the selective forcing of the tip (40) and surface together by the third transducer subsystem.
17. Apparatus as claimed in claim 14 and claim 16, wherein the second transducer subsystem applies energy to the surface via the tip (40) as the tip (40) and the surface are moved towards each other by the third transducer subsystem.
18. Apparatus as claimed in claim 17, wherein the second transducer subsystem applies energy to the surface to the surface via the tip (40) coincidentally with the tip (40) being brought into contact with the surface by the third transducer subsystem.
19. Apparatus as claimed in claim 14 and claim 16, wherein the second transducer subsystem applies energy to the surface via the tip (40) as the tip (40) and the surface are moved away from each other by the third transducer subsystem.
20. Apparatus as claimed in claim 19, wherein the second transducer subsystem applies energy to the surface via the tip (40) coincidentally with the tip (40) being moved out of contact with the surface by the third transducer subsystem.
21. Apparatus as claimed in any of claims 13 to 20, wherein the third transducer subsystem comprises a force field generator for selectively generating a force field acting on the tip (40) to urge the tip (40) and the surface together.
22. Apparatus as claimed in claim 21, wherein the force field generator moves the tip (40) into and out of contact with the surface by the selective generation of the force field.
23. Apparatus as claimed in claim 21 or claim 22, wherein the force field generator comprises an electric field generator (250).
24. Apparatus as claimed in claim 21 or claim 22, wherein the force field generator comprises a magnetic field generator.
25. A data storage device comprising a storage surface and an apparatus for writing data to and/or reading data from locations on the surface via the tip (40) as claimed in any claims 13 to 24.
26. A data processing system comprising a central processing unit and a data storage device as claimed in claim 25 connected to the central processing unit.

#### Patentansprüche

1. Verfahren zum Schreiben und/oder Lesen von Daten auf Positionen der Oberfläche eines Speichermediums mittels einer Spitze, wobei das Verfahren Folgendes umfasst:

- Bewegen der Spitze (40) zwischen den Posi-



tionen auf der Oberfläche;

- selektives Aufbringen von Energie auf die Oberfläche an jeder der Positionen mittels der Spitze (40) durch Betreiben eines Heizelementes (30) zum Heizen und/oder thermischen Rücklesen im Pulsmodus, wobei ein Cantilever-Sensor (10) das Heizelement (30) und die Spitze (40) umfasst;

und wobei das Verfahren **dadurch gekennzeichnet ist**, dass die Spitze (40) selektiv mit der Oberfläche zusammengebracht wird, wobei dies im Pulsmodus und in Synchronisation mit dem selektiven Aufbringen von Energie erfolgt.

2. Verfahren nach Anspruch 1, welches das alternierende Bewegen der Spitze (40) zur Oberfläche hin und von der Oberfläche weg umfasst.
3. Verfahren nach Anspruch 1 oder 2, welches das selektive Zusammenbringen von Spitze (40) und Oberfläche, zeitgleich mit dem selektiven Aufbringen von Energie auf die Oberfläche mittels der Spitze (40), umfasst.
4. Verfahren nach Anspruch 1 oder 2, welches das Versetzen des selektiven Aufbringens von Energie auf die Oberfläche relativ zum selektiven Zusammenbringen von Spitze (40) und Oberfläche umfasst.
5. Verfahren nach Anspruch 2 und 4, bei welchem das selektive Aufbringen von Energie auf die Oberfläche das Aufbringen von Energie auf die Oberfläche mittels der Spitze (40) umfasst, während die Spitze (40) und die Oberfläche aufeinander zu bewegt werden.
6. Verfahren nach Anspruch 5, bei welchem das selektive Aufbringen von Energie auf die Oberfläche das Aufbringen von Energie auf die Oberfläche mittels der Spitze (40) zeitgleich zur Berührung der Oberfläche durch die Spitze (40) umfasst.
7. Verfahren nach Anspruch 2 und 4, bei welchem das selektive Aufbringen von Energie auf die Oberfläche das Aufbringen von Energie auf die Oberfläche mittels der Spitze (40) umfasst, während die Spitze (40) und die Oberfläche voneinander weg bewegt werden.
8. Verfahren nach Anspruch 7, bei welchem das selektive Aufbringen von Energie auf die Oberfläche das Aufbringen von Energie auf die Oberfläche mittels der Spitze (40) zeitgleich zu dem Moment, in dem die Spitze (40) die Oberfläche verlässt, umfasst.
9. Verfahren nach einem der vorangegangenen Ansprüche, bei welchem das selektive Zusammenbringen von Spitze (40) und Oberfläche das selektive

Erzeugen eines auf die Spitze (40) wirkenden Kraftfeldes umfasst, welches die Spitze (40) und die Oberfläche aufeinander zu zwingt.

- 5 10. Verfahren nach Anspruch 9, welches durch selektives Erzeugen des Kraftfeldes das Bewegen der Spitze (40) in der Form umfasst, dass zwischen der Spitze (40) und der Oberfläche ein Kontakt hergestellt und wieder aufgehoben wird.
- 10 11. Verfahren nach Anspruch 9 oder 10, bei welchem das Kraftfeld ein elektrisches Feld umfasst.
- 15 12. Verfahren nach Anspruch 9 oder 10, bei welchem das Kraftfeld ein magnetisches Feld umfasst.
- 20 13. Einrichtung zum Schreiben und/oder Lesen von Daten auf Positionen der Oberfläche eines Speichermediums mittels einer Spitze, wobei die Einrichtung Folgendes umfasst:
  - einen Cantilever-Sensor (10), der die Spitze (40) und ein Heizelement (30) zum Heizen und/oder thermischen Rücklesen umfasst;
  - ein erstes Transducer-Untersystem zum Bewegen der Spitze (40) zwischen den Positionen der Oberfläche;
  - ein zweites Transducer-Untersystem zum selektiven Aufbringen von Energie auf jede Position der Oberfläche mittels der Spitze (40) durch Betreiben des Heizelementes (30) im Pulsmodus; und wobei die Einrichtung **dadurch gekennzeichnet ist**, dass sie des Weiteren ein drittes Transducer-Untersystem umfasst, zum selektiven Zusammenbringen von Spitze (40) und Oberfläche im Pulsmodus und in Synchronisation mit dem Aufbringen von Energie durch das zweite Transducer-Untersystem.
- 25 35 40 45 50 55 14. Einrichtung nach Anspruch 13, bei welcher das dritte Transducer-Untersystem die Spitze (40) alternierend zur Oberfläche hin und wieder weg bewegt, in Synchronisation mit dem Aufbringen von Energie durch das zweite Transducer-Untersystem.
15. Einrichtung nach Anspruch 13 oder 14, bei welcher das dritte Transducer-Untersystem die Spitze (40) und die Oberfläche selektiv und zeitgleich mit dem Aufbringen von Energie durch das zweite Transducer-Untersystem zusammenbringt.
16. Einrichtung nach Anspruch 13 oder 14, bei welcher das Aufbringen von Energie auf die Oberfläche durch das zweite Transducer-Untersystem relativ zum selektiven Zusammenbringen von Spitze (40) und Oberfläche durch das dritte Transducer-Untersystem versetzt ist.

17. Einrichtung nach Anspruch 14 und 16, bei welcher das zweite Transducer-Untersystem mittels der Spitze (40) Energie auf die Oberfläche aufbringt, während die Spitze (40) und die Oberfläche durch das dritte Transducer-Untersystem aufeinander zu bewegt werden.
18. Einrichtung nach Anspruch 17, bei welcher das zweite Transducer-Untersystem mittels der Spitze (40) Energie auf die Oberfläche aufbringt, zeitgleich zu dem Moment, in dem die Spitze (40) und die Oberfläche durch das dritte Transducer-Untersystem in Kontakt gebracht werden.
19. Einrichtung nach Anspruch 14 und 16, bei welcher das zweite Transducer-Untersystem mittels der Spitze (40) Energie auf die Oberfläche aufbringt, während die Spitze (40) und die Oberfläche durch das dritte Transducer-Untersystem voneinander weg bewegt werden.
20. Einrichtung nach Anspruch 19, bei welcher das zweite Transducer-Untersystem mittels der Spitze (40), zeitgleich zur Unterbrechung des Kontakts zwischen der Spitze (40) und der Oberfläche durch das dritte Transducer-Untersystem, Energie auf die Oberfläche aufbringt.
21. Einrichtung nach einem der Ansprüche 13 bis 20, bei welcher das dritte Transducer-Untersystem einen Kraftfeldgenerator zum selektiven Erzeugen eines auf die Spitze (40) wirkenden und diese mit der Oberfläche zusammenbringenden Kraftfeldes umfasst.
22. Einrichtung nach Anspruch 21, bei welcher der Kraftfeldgenerator die Spitze (40) so bewegt, dass durch das selektive Erzeugen des Kraftfeldes ein Kontakt zwischen der Spitze (40) und der Oberfläche hergestellt und wieder aufgehoben wird.
23. Einrichtung nach Anspruch 21 oder 22, bei welcher der Kraftfeldgenerator einen Generator (250) zur Erzeugung eines elektrischen Feldes umfasst.
24. Einrichtung nach Anspruch 21 oder 22, bei welcher der Kraftfeldgenerator einen Magnetfeldgenerator umfasst.
25. Datenspeichervorrichtung mit einer Speicheroberfläche und einer Einrichtung zum Schreiben und/oder Lesen von Daten auf Positionen der Oberfläche eines Speichermediums mittels der Spitze (40) nach einem der Ansprüche 13 bis 24.
26. Datenverarbeitungssystem mit einer Zentraleinheit (CPU) und einer mit der Zentraleinheit verbundenen Datenspeichervorrichtung nach Anspruch 25.

## Revendications

1. Procédé d'écriture de données sur des emplacements et/ou de lecture de données à partir d'emplacements sur une surface de support de mémorisation par l'intermédiaire d'une pointe, le procédé comprenant : le déplacement de la pointe (40) entre les emplacements sur la surface, et à chaque emplacement, l'application sélective d'énergie à la surface par l'intermédiaire de la pointe (40) en actionnant un élément de chauffage (30) en vue d'un chauffage et/ou en vue d'une relecture thermique dans un mode pulsé, où un capteur en porte-à-faux (10) comprend l'élément de chauffage (30) et la pointe (40), et caractérisé par le fait de forcer sélectivement la pointe (40) à proximité de la surface à la fois dans un mode pulsé et en synchronisme avec l'application sélective d'énergie.
2. Procédé selon la revendication 1, comprenant le fait de déplacer la pointe (40) alternativement vers la surface et à l'écart de celle-ci.
3. Procédé selon la revendication 1 ou la revendication 2, comprenant le fait de forcer sélectivement la pointe (40) et la surface ensemble en coïncidence avec l'application sélective d'énergie à la surface par l'intermédiaire de la pointe (40).
4. Procédé selon la revendication 1 ou la revendication 2, comprenant le fait de décaler l'application sélective d'énergie sur la surface par rapport au fait de forcer ensemble de manière sélective la pointe (40) et la surface.
5. Procédé selon la revendication 2 et la revendication 4, dans lequel l'application sélective d'énergie à la surface comprend l'application d'énergie à la surface par l'intermédiaire de la pointe (40) lorsque la pointe (40) et la surface sont rapprochées l'une de l'autre.
6. Procédé selon la revendication 5, dans lequel l'application sélective d'énergie à la surface comprend une application d'énergie à la surface par l'intermédiaire de la pointe (40) de manière coïncidente avec le fait que la pointe (40) entre en contact avec la surface.
7. Procédé selon la revendication 2 et la revendication 4, dans lequel l'application sélective d'énergie à la surface comprend l'application d'énergie à la surface par l'intermédiaire de la pointe (40) lorsque la pointe (40) et la surface sont écartées l'une de l'autre.
8. Procédé selon la revendication 7, dans lequel l'application sélective d'énergie à la surface comprend l'application d'énergie à la surface par l'intermédiaire de la pointe (40) en coïncidence avec le dégagement

de la pointe (40) de la surface.

9. Procédé selon l'une quelconque des revendications précédentes, dans lequel le fait de forcer sélectivement la pointe (40) et la surface ensemble comprend le fait de générer de manière sélective un champ de force agissant sur la pointe (40) afin de solliciter la pointe (40) et la surface ensemble. 5
10. Procédé selon la revendication 9, comprenant le fait de déplacer la pointe (40) en et hors de contact avec la surface grâce à la génération sélective du champ de force. 10
11. Procédé selon la revendication 9 ou la revendication 10, dans lequel le champ de force comprend un champ électrique. 15
12. Procédé selon la revendication 9 ou la revendication 10, dans lequel le champ de force comprend un champ magnétique. 20
13. Dispositif destiné à écrire des données sur des emplacements et/ou à lire des données à partir d'emplacements sur une surface de support de mémorisation par l'intermédiaire d'une pointe, le dispositif comprenant : un capteur en porte-à-faux (10) comprenant la pointe (40) et un élément de chauffage (30) destiné à un chauffage et/ou à une relecture thermique, un premier sous-système de transducteur destiné à déplacer la pointe (40) entre les emplacements sur la surface, un second sous-système de transducteur destiné à appliquer sélectivement de l'énergie à la surface par l'intermédiaire de la pointe (40) à chaque emplacement en actionnant l'élément de chauffage (30) dans un mode pulsé, et caractérisé en ce qu'il comprend en outre un troisième sous-système de transducteur destiné à forcer de manière sélective la pointe (40) et la surface ensemble dans un mode pulsé et en synchronisme avec l'application d'énergie par le sous-système de transducteur. 25 30 35 40
14. Dispositif selon la revendication 13, dans lequel le troisième sous-système de transducteur déplace la pointe (40) alternativement vers la surface et à l'écart de la surface en synchronisme avec l'application d'énergie par le second sous-système de transducteur. 45
15. Dispositif selon la revendication 13 ou la revendication 14, dans lequel le troisième sous-système de transducteur force sélectivement la pointe (40) et la surface ensemble en coïncidence avec l'application d'énergie par le second sous-système de transducteur. 50
16. Dispositif selon la revendication 13 ou la revendication 14, dans lequel l'application d'énergie à la surface par le second sous-système de transducteur est décalée par rapport au fait de forcer sélectivement la pointe (40) et la surface ensemble grâce au troisième sous-système de transducteur. 55
17. Dispositif selon la revendication 14 et la revendication 16, dans lequel le second sous-système de transducteur applique de l'énergie à la surface par l'intermédiaire de la pointe (40) lorsque la pointe (40) et la surface sont rapprochées l'une de l'autre par le troisième sous-système de transducteur.
18. Dispositif selon la revendication 17, dans lequel le second sous-système de transducteur applique de l'énergie à la surface par l'intermédiaire de la pointe (40) en coïncidence avec la mise en contact de la pointe (40) avec la surface par le troisième sous-système de transducteur.
19. Dispositif selon la revendication 14 et la revendication 16, dans lequel le second sous-système de transducteur applique de l'énergie à la surface par l'intermédiaire de la pointe (40) lorsque la pointe (40) et la surface sont écartées l'une de l'autre par le troisième sous-système de transducteur.
20. Dispositif selon la revendication 19, dans lequel le second sous-système de transducteur applique de l'énergie à la surface par l'intermédiaire de la pointe (40) en coïncidence avec la mise hors contact de la pointe (40) et de la surface grâce au troisième sous-système de transducteur.
21. Dispositif selon l'une quelconque des revendications 13 à 20, dans lequel le troisième sous-système de transducteur comprend un générateur de champ de force destiné à générer sélectivement un champ de force agissant sur la pointe (40) pour solliciter ensemble la pointe (40) et la surface.
22. Dispositif selon la revendication 21, dans lequel le générateur de champ de force déplace la pointe (40) en et hors de contact avec la surface grâce à la génération sélective du champ de force.
23. Dispositif selon la revendication 21 ou la revendication 22, dans lequel le générateur de champ de force comprend un générateur de champ électrique (250).
24. Dispositif selon la revendication 21 ou la revendication 22, dans lequel le générateur de champ de force comprend un générateur de champ magnétique.
25. Dispositif de mémorisation de données comprenant une surface de mémorisation et un dispositif destiné à écrire des données sur des emplacements et/ou lire des données à partir d'emplacements sur la sur-

face par l'intermédiaire de la pointe (40) selon l'une quelconque des revendications 13 à 24.

26. Système de traitement de données comprenant une unité de traitement centrale et un dispositif de mémorisation de données selon la revendication 25 relié à l'unité de traitement centrale.

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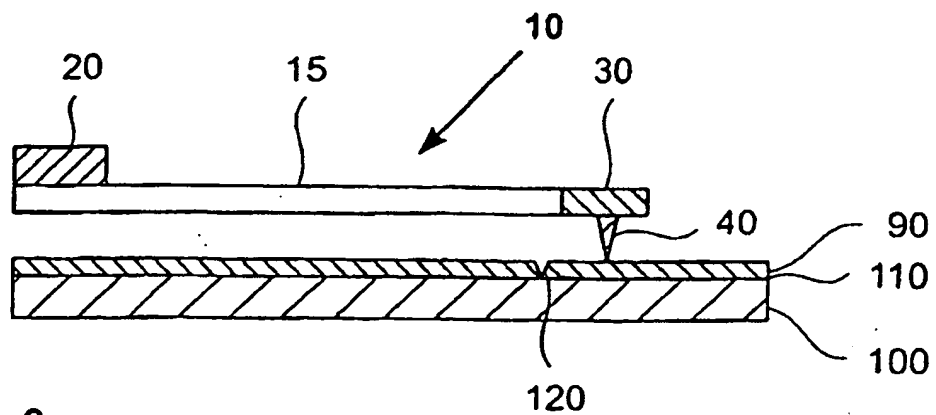
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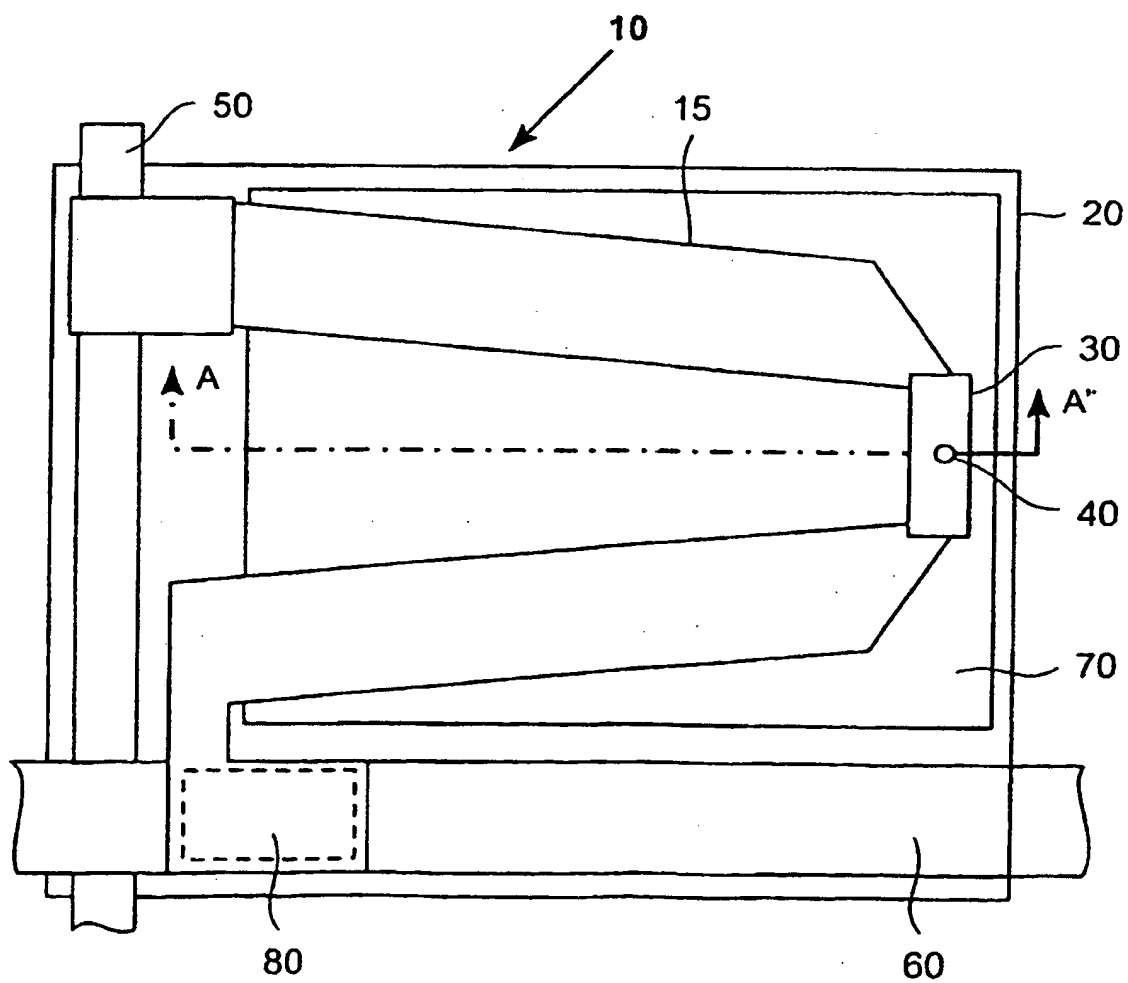
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**Fig. 2**



**Fig. 1**

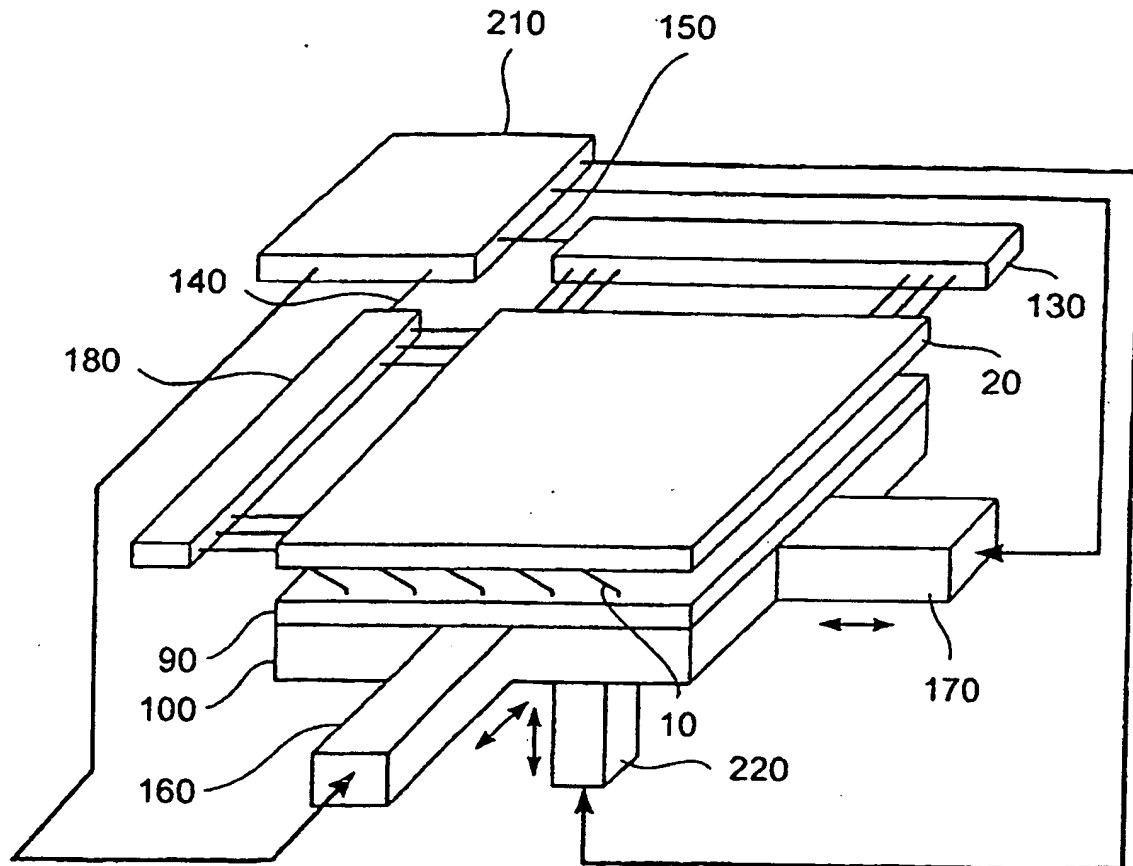


Fig. 3

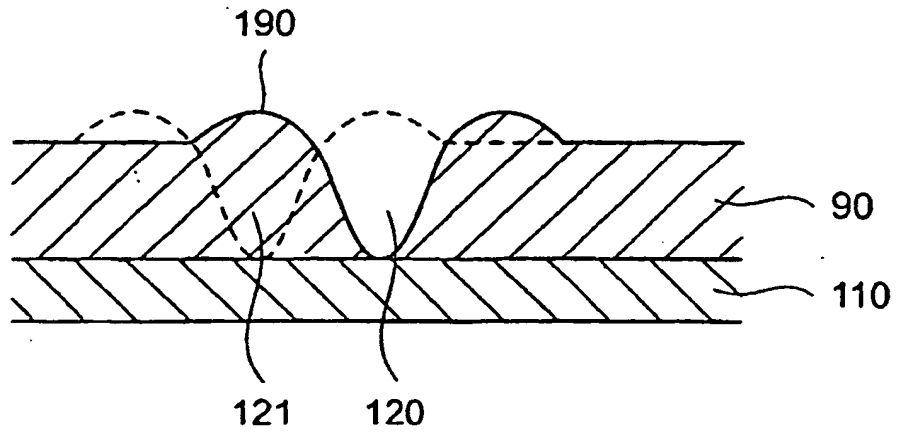


Fig. 4

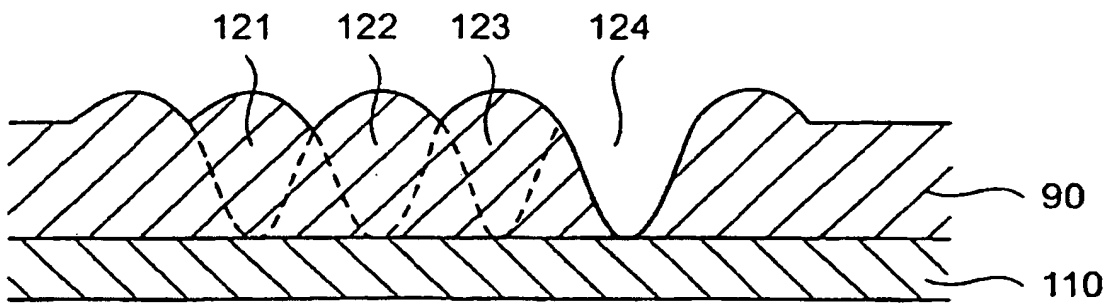


Fig. 5

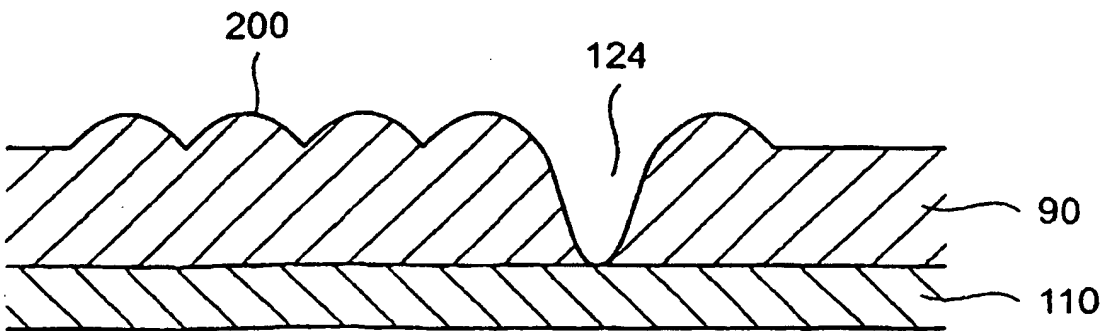


Fig. 6

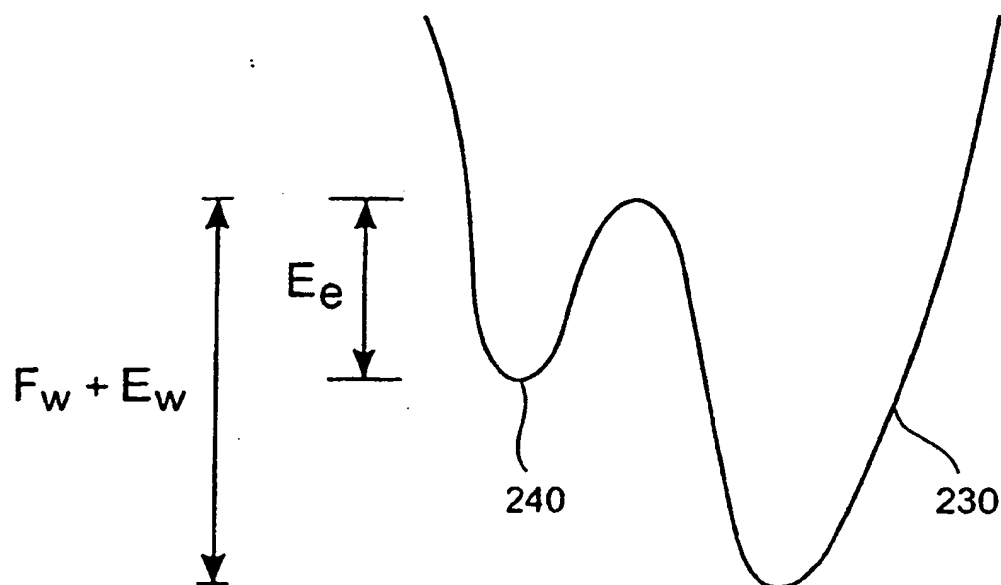
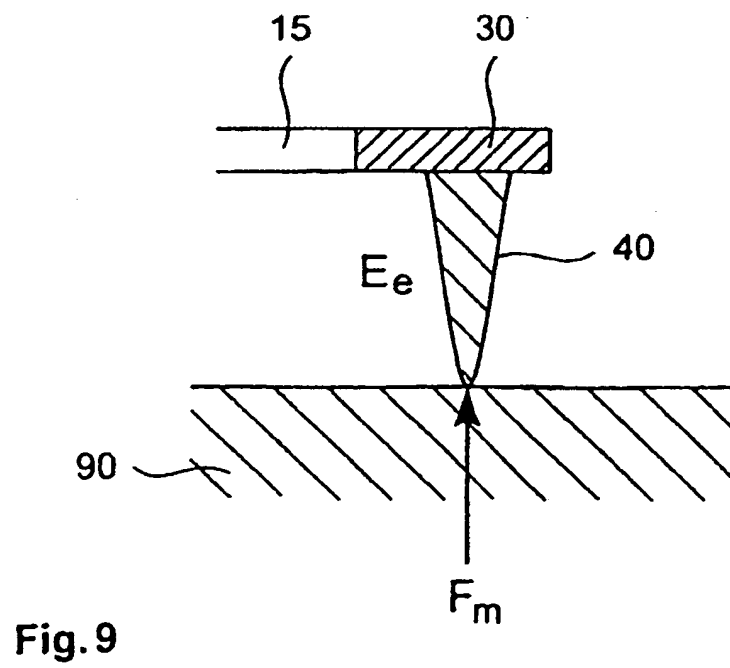
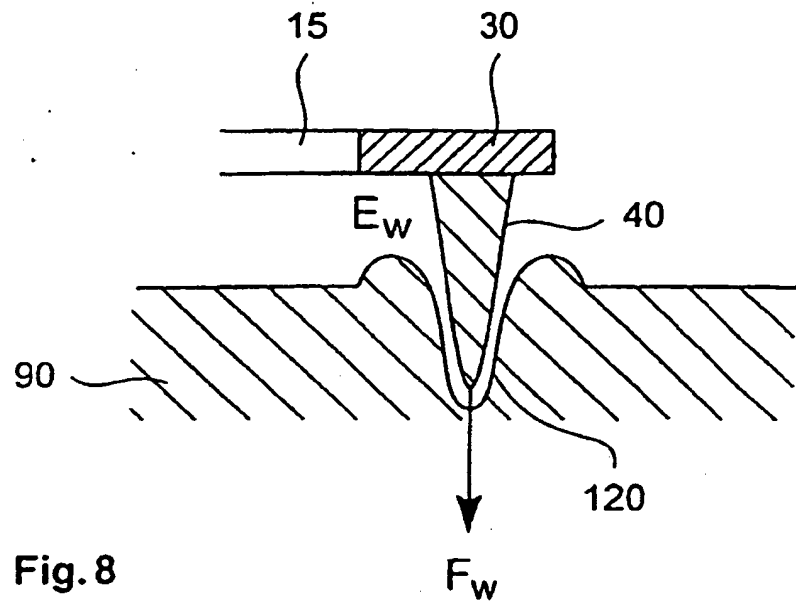


Fig. 7





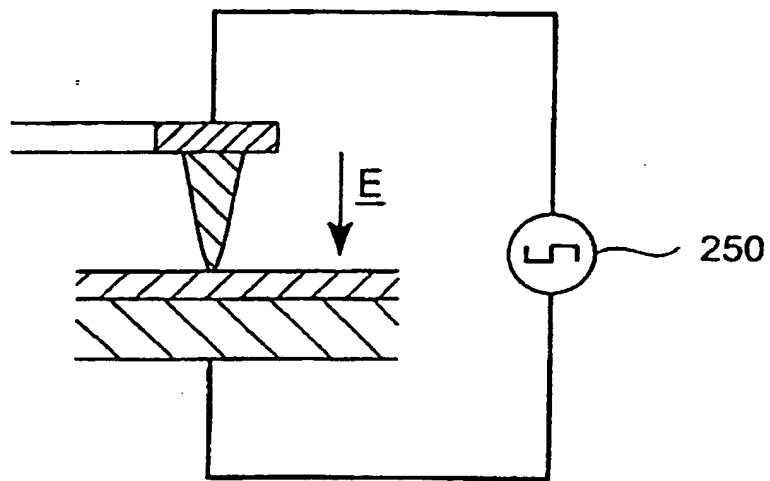


Fig. 10

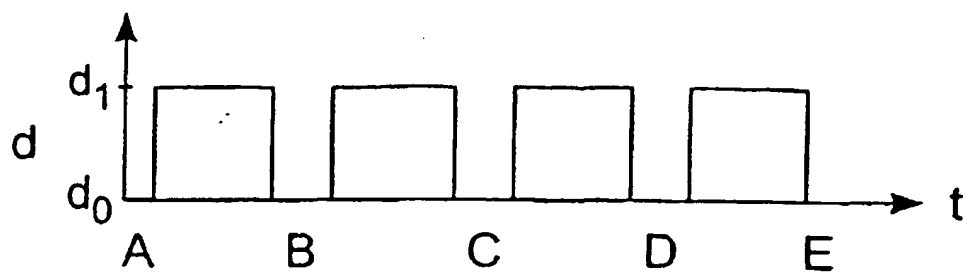


Fig. 11A

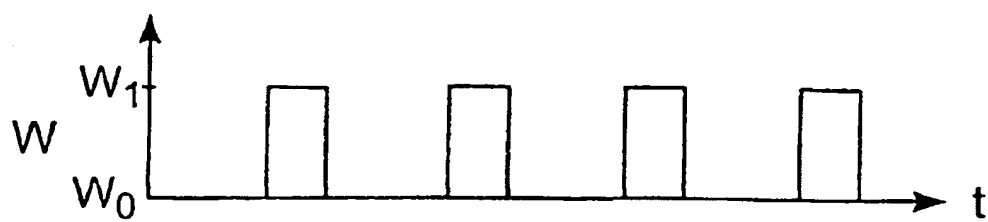


Fig. 11B

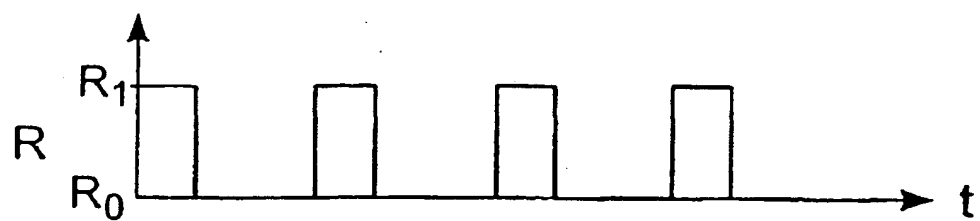


Fig. 11C

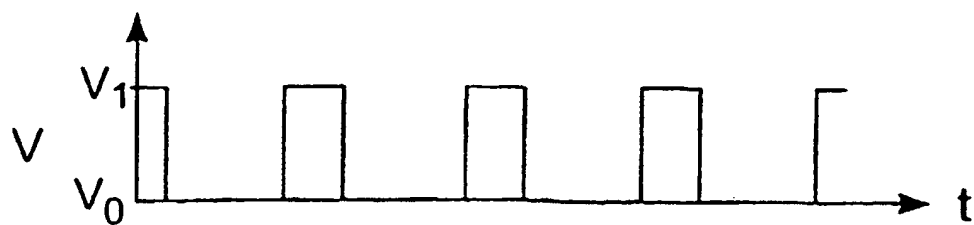


Fig. 11D